Convert 1 to 5V signal to 4- to 20-mA output

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Despite the long-predicted demise of the 4- to 20-mA current loop, this analog interface is still the most common method of connecting current-loop sources to a sensing circuit. This interface requires the conversion of a voltage signal—typically, 1 to 5V—to a 4- to 20-mA output. Stringent accuracy requirements dictate the use of either expensive precision resistors or a trimming potentiometer to calibrate out the initial error of less precise devices to meet the design goals.

Neither technique is optimal in today's surface-mounted, automatic-test-equipment-driven production environment. It's difficult to get precise resistors in surface-mount packages, and trimming potentiometers require human intervention, a requirement that is incompatible with production goals.

The Linear Technology LT5400quad matched resistor network helps to solve these issues in a simple circuit that requires no trim adjustments but achieves a total error of less than 0.2% (**Figure 1**). The circuit uses two amplifier stages to exploit the unique matching characteristics of the LT5400. The first stage applies a 1 to 5V output—typically, from a DAC—to the noninverting input of op amp IC_{1A}. This voltage sets the current through R_1 to exactly V_{IN}/R_1 through FET Q_2. The same current is pulled down through R_2, so the voltage at the bottom of R_2 is the 24V loop supply minus the input voltage.

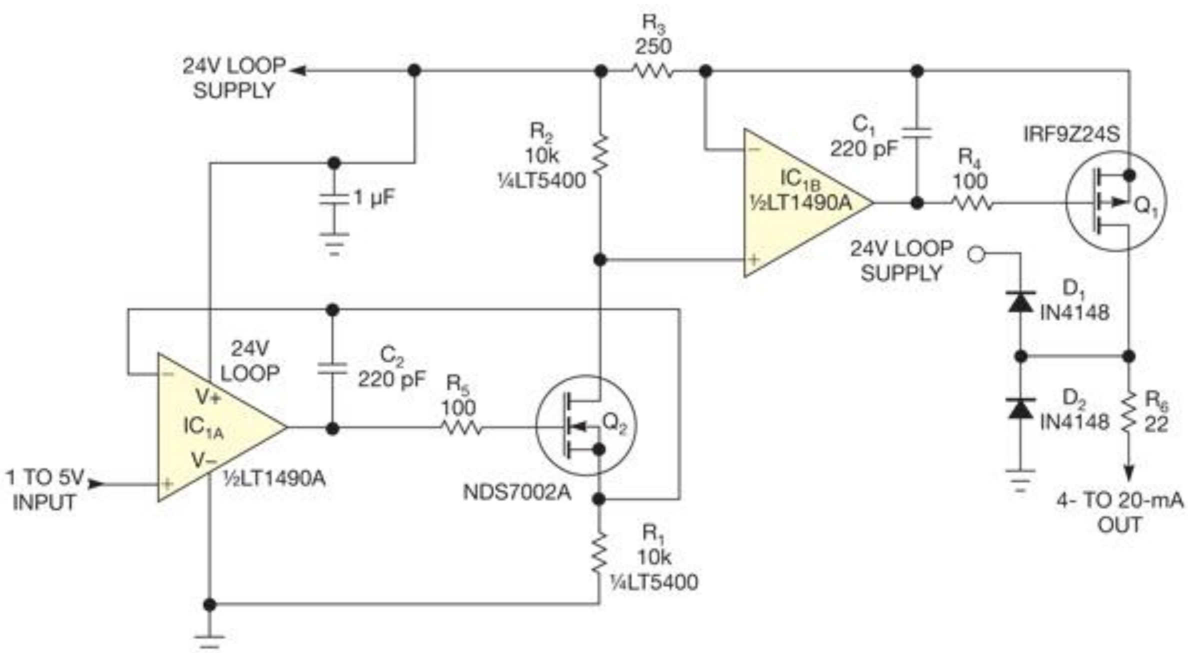

Figure 1 Precision matched resistors provide accurate voltage-to-current conversion.

This portion of the circuit has three main error sources: the matching of $R_1$and R_2, IC_{1A}'s offset voltage, and Q_2's leakage. The exact values of R_1 and $R_2$are not critical, but they must exactly match each other. The LT5400A grade achieves this goal with ±0.01% error. The LT1490A has less-than-700-µV offset voltage over 0 to 70°C. This voltage contributes 0.07% error at an input voltage of 1V. The NDS7002A has a leakage current of 10 nA, although it is usually much less. This leakage current represents an error of 0.001%.

The second stage holds the voltage on R_3 equal to the voltage on R_2 by pulling current through Q_1. Because the voltage across R_2 equals the input voltage, the current through Q_1 is exactly the input voltage divided by R_3. By using a precision 250Ω current shunt for R_3, the current accurately tracks the input voltage.

The error sources for the second stage are R_3's value, IC_{1B}'s offset voltage, and Q_1's leakage current. Resistor R_3 directly sets the output current, so its value is crucial to the precision of the circuit. This circuit takes advantage of the commonly used 250Ω current-loop-completion shunt resistor. The Riedon SF-2 part in the **figure** has 0.1% initial accuracy and low temperature drift. As in the first stage, offset voltage contributes no more than 0.07% error. Q_1 has less than 100-nA leakage, yielding a maximum error of 0.0025%.

Total output error is better than 0.2% without any trimming. Current-sensing resistor R_3 is the dominant source of error. If you use a higher-quality device, such as the Vishay PLT series, you can achieve an accuracy of 0.1%. Current-loop outputs are subject to considerable stresses in use. Diodes D_1 and D_2 from the output to the 24V loop supply and ground help protect Q_1; R_6 provides some isolation. You can achieve more isolation by increasing the value of R_6, with the trade-off of some compliance voltage at the output. If the maximum output-voltage requirement is less than 10V, you can increase R_6's value to 100Ω, affording even more isolation from output stress. If your design requires increased protection, you can fit a transient-voltage suppressor to the output with some loss of accuracy due to leakage current.

This design uses only two of the four matched resistors in the LT5400package. You can use the other two for other circuit functions, such as a precision inverter, or another 4- to 20-mA converter. Alternatively, you can place the other resistors in parallel with $R_1$and R_2. This approach lowers the resistor's statistical error contribution by the square root of two.